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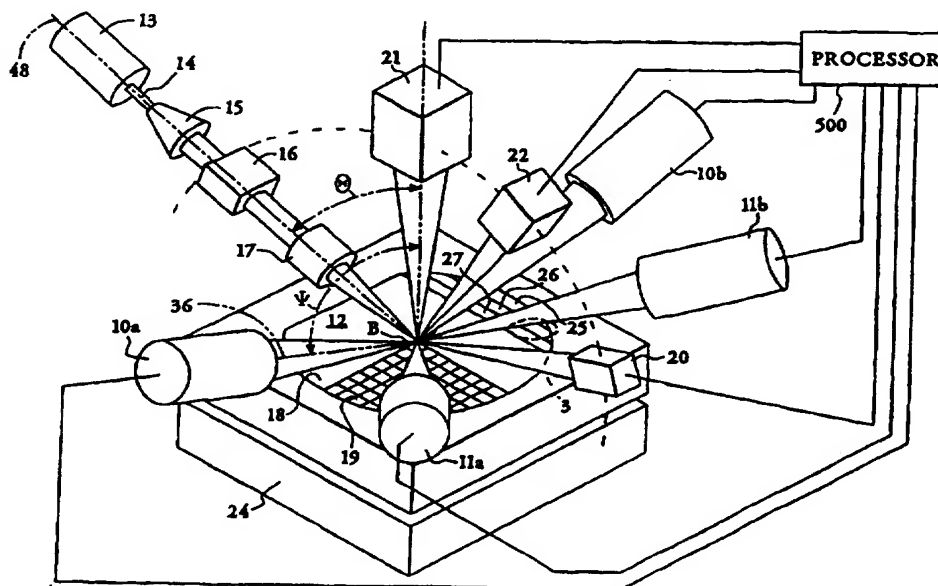
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(54) Title: OPTICAL SCANNING SYSTEM FOR SURFACE INSPECTION



## (57) Abstract

In an optical scanning system (200) for detecting particles and pattern defects on a sample surface (240), a light beam (238) is focused to an illuminated spot on the surface and the spot is scanned across a scan line. A detector (11b) is positioned adjacent to the surface to collect scattered light from the spot where the detector includes a one- or two-dimensional array of sensors. Light scattered from the illuminated spot at each of a plurality of positions along the scan line is focused onto a corresponding sensor in the array. A plurality of detectors symmetrically placed with respect to the illuminating beam detect laterally and forward scattered light from the spot.

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## OPTICAL SCANNING SYSTEM FOR SURFACE INSPECTION

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### BACKGROUND OF THE INVENTION

10 The present invention pertains to the field of optical surface inspection. Specifically, the present invention pertains to illumination and light collection optics for inspecting semiconductor wafers and the like.

15 Monitoring anomalies, such as pattern defects and particulate contamination, during the manufacture of semiconductor wafers is an important factor in increasing production yields. Numerous types of defects and contamination, especially particles, can occur on a wafer's surface. Determining the presence, location and type of an anomaly on the wafer surface can aid in both  
20 locating process steps at which the anomaly occurred and determining whether a wafer should be discarded.

Originally, anomalies were monitored manually by visual inspection of wafer surfaces for the presence of particulate matter. These anomalies, usually dust or  
25 microscopic silicon particles, caused many of the wafer pattern defects. However, manual inspection proved time-consuming and unreliable due to operator errors or an operator's inability to observe certain defects. The ever increasing size of the wafer surface, along with

the decreasing dimensions of the components thereon, resulted in a sharp increase in the number of components on the wafer's surface. The need for automation became manifest.

5       To decrease the time required to inspect wafer surfaces, many automatic inspection systems were introduced. A substantial majority of these automatic inspection systems detect anomalies based on the scattering of light. For example, see U.S. Patent No.  
10   4,601,576 to L. Galbraith, assigned to the assignee of the present invention. These systems include two major components: illumination optics and collection-detection optics. Illumination optics generally consists of scanning a wafer surface with a coherent source of  
15   light, e.g., a laser. Anomalies present on the wafer's surface scatter incident light. The collection optics detect the scattered light with reference to the known beam position. The scattered light is then converted to electrical signals which can be measured, counted and  
20   displayed as bright spots on an oscilloscope or other monitor.

      The illumination optics plays a major role in establishing the detection sensitivity of the inspection system. The sensitivity is dependent upon the size of  
25   the spot scanned on the wafer and the illumination angle. The smaller the spot size, the more sensitive the system is to detecting anomalies. However, decreasing the spot size increases the time required to scan the wafer surface and therefore reduces throughput.

30       The sensitivity of both the illumination and collection-detection optics is dependent upon the texture of the surface of the wafer illuminated. If the surface illuminated is patterned, this reduces the sensitivity of the system because such areas produce  
35   scatter which makes it difficult to determine the

presence of an anomaly. To abrogate scatter due to patterned features, the angle of incidence of the spot on the surface is increased, with respect to the normal to the surface. However, too great of an angle, i.e., a grazing angle with respect to the surface, will also reduce the sensitivity of the system. Moreover, increasing the angle of incidence, increases the effective size of the spot, thereby reducing the sensitivity of the system. Thus, a trade-off exists between sensitivity and inspection rate of the system. The sensitivity of the collection-detection optics is generally a factor of the detector's azimuthal position with respect to the scanning beam and elevation.

Accordingly, many illumination and collection-detection techniques have been proposed that take advantage of the aforementioned concepts. In addition, efforts have been made to provide for constant scanning of the wafer's surface to further increase the speed of the inspection. In U.S. Patent No. 5, 317,380, Allemand discloses a beam of laser light brought to focus as an arcuate scan line on a surface, at a grazing angle of incidence. A pair of light detectors are provided to collect light which is scattered away from the beam in a forward direction so that the angle of collection is constant over the entire scan line.

U.S. Patent No. 4,912,487 to Porter et al. discloses a laser pattern writing and inspection system that illuminates a target surface with an argon ion laser beam. An acousto-optical deflector is driven with a chirp signal and placed in the path of the beam to cause it to sweep out raster scan lines. The target is placed on a stage capable of bi-directional movement. The beam has an angle of incidence normal to the target and the stage moves so that it is scanned along adjacent contiguous strips of equal width.

U.S. Patent No. 4,889,998 to Hayano et al., discloses an apparatus and method for detecting foreign particles on a pellicle using a beam of light that is scanned across the pellicle with light detected by a plurality of detectors grouped in pairs. Two pairs of detectors are positioned to collect rearwardly scattered light. The difference in intensity of scattered light detected by each detector is monitored, whereby the position of the particle on the pellicle is determined by analyzing the intensity variations.

In U.S. Patent No. 4,898,471 to Stonestrom et al., an apparatus and method for detecting particles on a patterned surface is disclosed wherein a single light beam is scanned, at a grazing angle of incidence, across the surface. The surface contains a plurality of identical dies with streets between them. With the beam scanning parallel to the streets, a single channel collection system detects scattered light from an azimuthal angle that maximizes particle signals while reducing pattern signals. A processor constructs templates from the detected light which corresponds to individual dies and then compares the templates to identify particles on the dies.

In U.S. Patent No. 4,617,427, Koizumi et al., a wafer is mounted on a feed stage connected to a rotary drive which provides a constant speed helical scan of a wafer surface. An S-polarized laser beam is scanned thereon at varying angles of incidence. The angle of incidence is dependent upon whether the wafer is smooth or patterned. A single detector is positioned perpendicular to the wafer's surface for collecting scattered light and includes a variable polarization filter that attenuates scattered light in an S polarization state, when the surface is patterned, and does not attenuate light if the wafer is smooth.

In U.S. Patent No. 4,441,124 to Heebner, a laser is scanned over the surface of a wafer at an angle normal thereto. The laser beam is scanned by deflecting it with a galvanometer and an acousto-optic deflector in  
5 synchronization with the scanning beam rate of a video monitor. A photodetector employing a ring-type collection lens monitors the intensity of light scattered substantially along the wafer surface. This arrangement was employed to take advantage of the  
10 finding that a patterned wafer having no particulate matter thereon will scatter substantially no light along the wafer surface, while a wafer having particulate matter on it will scatter a portion of the light impinging thereon along the surface.

15 Another particle detection apparatus and method is disclosed in U.S. Patent No. 4,391,524, to Steigmeier et al., wherein a laser beam is scanned at an angle normal to the wafer's surface. In addition to rotating, the wafer stage is provided with movement along one axis  
20 that results in the wafer being scanned in a spiral fashion. A single detector is positioned perpendicular to the surface to collect scattered light. Threshold circuitry is employed to discriminate between the defects monitored.

25 It is an object of the present invention to provide a high-speed apparatus which is capable of scanning a laser beam across the surface of either a patterned or unpatterned wafer to detect anomalies thereon with sizes on the order of a fraction of a micron.

30 It is a further object of the present invention to classify detected anomalies and determine their size while increasing the confidence and accuracy of the detection system by reducing false counts.

SUMMARY OF THE INVENTION

These objects have been achieved with an apparatus and method for detecting anomalies of sub-micron size, including pattern defects and particulate contaminants, on both patterned and unpatterned wafer surfaces. For the purposes of this application, a particulate contaminant is defined as foreign material resting on a surface, generally protruding out of the plane of the surface. A pattern defect may be in or below the plane of the surface and is usually induced by contaminants during a photolithographic processing step or caused by crystal defects in the surface.

One aspect of the invention is directed towards an optical scanning system for detection of anomalies, such as particles and pattern defects on a surface, comprising means for directing a focused beam of light onto a sample surface to produce an illuminated spot thereon and means for scanning the spot across the surface along a first scan line. The system further comprises a first detector positioned adjacent to said surface to collect scattered light from the spot wherein the detector includes a one-dimensional or two-dimensional array of sensors and means for focusing scattered light from the illuminated spot at each of a plurality of positions along the scan line onto a corresponding sensor in the array.

Another aspect of the invention is directed towards an optical scanning method for detection of anomalies, such as particles and patterns on a surface, comprising the steps of directing a focused beam of light onto a sample surface to produce an illuminated spot thereon; scanning a spot across the surface along a first scan line; positioning a first detector adjacent to said surface to collect scattered light from the spot, wherein the detector includes a one-dimensional or two-



dimensional array of sensors; and focusing scattered light from the illuminated spot at each position along the scan line onto a corresponding sensor in the array.

#### BRIEF DESCRIPTION OF THE DRAWINGS

5        Fig. 1 is a simplified perspective plan view of the illumination and collection optics of the present invention.

      Fig. 2 is a top view of the illumination and collection optics shown in Fig. 1.

10       Fig. 3 is a detailed view showing the scan path of a spot on a wafer surface.

      Fig. 4 is a detailed view of a collection channel shown in Fig. 1.

15       Figs. 5A - 5B is a plan view showing a polarization scheme employed by the present invention.

      Fig. 6 is a graph of an electrical signal amplitude (I) versus beam scan position (X) on a wafer produced by the method of the present invention using the apparatus shown in Fig. 1.

20       Figs. 7A - 7E is a top view of a display derived from a scan of the wafer, as shown in Fig. 3.

      Fig. 8 is a plan view of an imaging channel shown in Fig. 1.

25       Fig. 9A is a schematic view of an elliptical-shaped illuminated area or spot on a surface to be inspected to illustrate the invention.

      Fig. 9B is a graphical illustration of the illumination intensity across the width or short axis of the elliptical spot of Fig. 9A for defining a boundary of the spot and to illustrate a point spread function of the illumination beam.

30

      Fig. 9C is a schematic view of three positions of an illuminated spot on a surface to be inspected to

illustrate the scanning and data gathering process of the system of this invention.

Fig. 10 shows partially in perspective and partially in block diagram form a system for inspecting anomalies of a semiconductor wafer surface to illustrate the preferred embodiment of the invention.

Fig. 11 is a block diagram of the imaging channel two-dimensional array detector of Fig. 8 and of a processor for controlling the detector and for synchronizing the transfer of signals in the detector with the scanning of light beam in Fig. 1 and 10.

For simplicity in description, identical components are identified by the same numerals in this application.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention, as shown in Fig. 1 is based on the discovery that the scattering cross section of an anomaly on a patterned surface is asymmetrical. This in part is due to the asymmetry of the anomaly itself, or, in the case of particulate contaminants, the pattern on which a particulate rests changing the effective scattering cross section of the particle. Taking advantage of this discovery, a plurality of detectors are provided that includes groups of collector channels symmetrically disposed about the circumference of the surface. Although a greater number of collector channels may be employed in each group, the preferred embodiment uses two groups of two collector channels, 10a-b and 11a-b, disposed symmetrically about the wafer surface 12 so that each collector channel within a pair is located at the same azimuthal angle on opposite sides of the scan line, indicated by the line B. With collector channels positioned symmetrically in the azimuth, a substantial reduction in false counts can be obtained. For example, an anomaly having a symmetrical

scattering cross section, will cause scattered light to impinge on a pair of collector channels, disposed symmetrically in the azimuth, with the same intensity. Anomalies with an asymmetrical scattering cross section will impinge on the same pair of collector channels with varying intensities. By comparing data representing the intensity of light impinging on symmetrically disposed collector channels, signals which are in common, such a pattern signals, may be discarded. This provides a high confidence level that the resulting signals are in fact anomalies, and not due to random scattering by surface features. The data from the channels is compared by performing various algorithms and logical operations, e.g., OR, AND and XOR. In addition, examining the data concerning the anomalies having unidentical signals in the two channels allows determining the shape and/or composition of them.

As shown in Fig. 1, a light source 13, typically a laser, emits a beam 14. Beam 14 is directed towards the pre-deflector optics 15, which consists of a half wave-plate, a spatial filter and several cylindrical lenses, in order to produce an elliptical beam with a desired polarization that is compatible with the scanner 16. The pre-deflector optics 15 expands the beam 14 to obtain the appropriate numerical aperture. The post-deflector optics 17 includes several cylindrical lenses and an air slit. Finally, the beam 14 is brought into focus on the a wafer surface 12 and scanned along the direction, in the plane of the wafer surface 12, indicated by B, perpendicular to the optical axis of the beam 14. The type of deflector employed in the apparatus is application dependent and may include a polygonal mirror or galvonmeter. However, in the preferred embodiment, deflector 16 is an Acousto-optic Deflector. The wafer surface 12 may be smooth 18 or

patterned 19. In addition to the collector channels 10a-b and 11a-b, described above, detector channels are provided which include a reflectivity/autoposition channel 20, an imaging channel 21 and an alignment/registration channel 22, each of which are discussed more fully below.

The beam 14 has a wavelength of 488 nm and is produced by an Argon ion laser. The optical axis 48 of the beam 14 is directed onto the wafer surface 12 at an angle,  $\Theta$ . This angle,  $\Theta$ , is in the range of 55-85° with respect to the normal to the wafer surface 12, depending on the application. The scanning means includes the deflector 16 and the translation stage 24 upon which the wafer rests. The position of the wafer on the stage 24 is maintained in any convenient manner, e.g., vacuum suction. The stage 24 moves to partition the surface 12 into striped regions, shown as 25, 26 and 27 with the deflector 16 moving the beam across the width of the striped regions.

Referring to Fig. 2, the grazing angle of the beam 14 produces an elliptical spot 23 on the wafer surface 12, having a major axis perpendicular to the scan line. The deflector 16 scans the spot 23 across a short scan line equal in length to the width of striped region 25 to produce specularly reflected and scattered light. The spot 23 is scanned in the direction indicated, as the stage 24 moves the wafer perpendicular to the scan line. This results in the spot 23 moving within the striped region 25, as shown in Fig. 3. The preferred embodiment scans in only one direction as indicated by scan path 28. Scan path 28 has an effective start location at 29 and the spot 22 moves to the right therefrom until it reaches the border 31 of striped region 25. Upon reaching border 31, the spot 23 the stage 24 moves perpendicular to the scan direction and

the spot assumes a new start position 30 and moves parallel to scan line 28, along scan line 32. The deflector 16 continues to scan the spot 23 in this fashion along the entire length of striped region 25.

5 Upon completion of the scan of striped region 25, the stage 24 moves the wafer to permit the scanning of the adjacent striped region 26. The effective start location 33 is positioned so that the stage 24 shall move perpendicular to each scan line in a direction

10 opposite to that when scanning striped region 24, thereby forming a serpentine scan. This is demonstrated by scan paths 34 and 35. Moving the stage 24 to scan adjacent striped regions in opposite directions substantially reduces the amount of mechanical movement

15 of the stage while increasing the number of wafers scanned per hour.

Referring to Figs. 1 and 3, light scattered from the wafer surface 12 is detected by a plurality of detectors, including collector channels 10a-b and 11a-b.

20 An important aspect of the collector channels is that they collect light over a fixed solid angle, dependent upon, inter alia, the elevational and azimuthal angle of the channel. The optical axis of each collection channel is positioned at an angle of elevation  $\psi$  in the

25 range of 70-90 degrees, with respect to the normal to the surface 12. As discussed above collector channels 10a and 10b are symmetrically positioned at the same azimuthal angle with respect to beam 14, on opposite sides of the scan line. Collector channels 10a and 10b

30 are positioned, with respect to the beam 14, at an azimuthal angle  $\Phi_1$  in the range of about 75 to about 105 degrees to collect laterally scattered light. Laterally scattered light is defined as light scattered at azimuthal angles in the range of about 75 to about 105

35 degrees, with respect to beam 14. Similar to collector

channels 10a and 10b, channels 11a and 11b are positioned on opposite sides of the scan line at the same azimuthal angle; however, the azimuthal angles  $\Phi_2$  of channels 11a and 11b are in the range of 30 to 60 degrees, to collect forwardly scattered light. Forwardly scattered light is defined as light scattered at azimuthal angles in the range of 30 to 60 degrees.

Providing the groups of collector channels, at differing azimuthal angles, facilitates classifying detected anomalies, by taking advantage of a discovery that laterally scattered light is more sensitive to detecting pattern defects, and forwardly scattered light is more sensitive to detecting particulate contaminants. To that end, channels 10a and 10b are positioned to collect laterally scattered light, representing pattern defects, and channels 11a and 11b are provided collect forwardly scattered light, representing particulate contamination.

Referring to Fig. 4, each collector channel 10a-b and 11a-b includes a lens system 113 that collects scattered light. A series of mirrors 114a-c reflect the light so that it is imaged onto a photomultiplier tube (PMT) 115. The PMT 115 converts the light impinging thereon into an electrical signal having a voltage level that is proportional to the light intensity. Positioned at the Fourier transform plane is a programmable spatial filter 116 and a variable aperture stop 117. The programmable spatial filter 116 allows the system to take advantage of spatial filtering when periodic features on the surface 12 are scanned. In addition to the angle of elevation and the azimuthal angle of each channel, the variable aperture stop permits varying the elevational collection angle by limiting the light introduced into the collector channel, in accordance with the geometry of the features on the wafer surface 12. Also located

proximate to the Fourier transform plane is a variable polarization filter 118. It should be noted, that it is also possible to place a PMT directly at the Fourier transform plane.

5 Referring to Fig. 5, it was found that by employing the following polarization schemes, the signal to background of the system could be substantially improved. To obtain optimum signal to background, the polarization scheme employed by the system is surface  
10 dependent. It may also be used to determine the composition of the anomaly, e.g., as composed of metallic or dielectric material. With respect to pattern defects, the polarizing element included in the post-scanner optics 17 will place the beam 14 in a state  
15 of either P or S polarization. A beam is in a state of S polarization when its electrical field is perpendicular to the plane of incidence. The plane of incidence is parallel to the plane of the paper. It is defined by the surface 12, beam 14 and reflected beam  
20 14b. A vector representation of the beam is shown by a  $\vec{k}$  vector representing the direction of propagation. The magnetic field is shown as the  $\vec{H}$  vector. The electric field vector is shown as being perpendicular to the plane of incidence by representing it with a dot  $\vec{E}$ . A  
25 beam is in a state of P polarization when the electric field is in the plane of incidence. This is shown in Fig. 5B where the beam 14 is shown in vector form with a propagation vector  $\vec{k}$ , a magnetic field vector shown as a dot  $\vec{H}$  and the electric field vector  $\vec{E}$ , perpendicular  
30 to the propagation vector  $\vec{k}$ . Referring also to Fig. 4, if beam 14 is incident on the surface 12 in an S state of polarization, the variable polarization filter 118 would allow scattered light in an S state of  
35 polarization to pass through it and attenuate all other scattered light. For example, both non-polarized or P

polarized light would be attenuated and S polarized light would be collected by the collector channels. Alternatively, optimizing the detection of pattern defects could be accomplished with an S polarized beam  
5 14 and the polarization filter allowing all scattered light to pass through it. If the beam 14 is in a P polarization state, the variable polarization filter 118 would allow P polarized light to pass through it and would attenuate all other scattered light. Alternatively,  
10 ly, the polarization filter could allow all scattered light to be detected when beam 14 is P polarized. This also optimizes detection of pattern defects. Similarly, if the beam 14 were incident on the surface 12 with either a left or right handed circular polarization, the  
15 collector channels would be very sensitive to detecting pattern defects by allowing the polarization filter to pass all the collected light therethrough.

To detect particulate contaminants on a pattern surface, the variable polarization filter 118 would  
20 attenuate scattered light that is not in a P state of polarization, if the beam were S polarized. Were beam 14 in a P state of polarization, the collector channels would collect scattered light that was S polarized, whereby the variable polarization filter 118 would  
25 attenuate all other scattered light impinging on the channel. For detecting particulates on a bare surface, beam 14 would be in a P state of polarization and the collector channels would collect all light scattered therefrom to maximize the capture rate.

30 Referring to Fig. 6, an electrical signal 37 is produced by one of the inspection channels corresponding to an intensity I of collected scattered light as a beam scans over a scan path. The abscissa X of the graph in Fig. 5 represents the spatial position of the beam along  
35 the scan path. Signal 37 is made of a plurality of



discrete samples taken during the scan, e.g., a plurality of scan lines, each of which were scanned at different positions on a surface.

Figs. 1 and 7A-E is an example of an interchannel communication scheme. Shown therein is a resulting display of a map constructed by a processor 500 from the signals produced by the inspection channels. For purposes of this example, Figs. 7A and 7B represent scattered light detected by a pair of collector channels. The light detected from the surface consists of a plurality of signals, shown as spots 38. These spots may represent anomalies or false positives: light detected from features or other non-anomalies present on the surface. The spots 38 may be stored digitally in the processor memory at addresses corresponding to spatial positions on the surface. The processor 500 compares the data stored in memory at addresses represented by the map shown in Fig. 7A with the data stored in memory represented by the map shown in Fig. 7B. The data can be compared by performing various algorithmic or logical operations on it. A logical OR operation maximizes the capture rate at the expense of a potential increase in false counts by storing all anomalies detected between both channels in memory. The composite map shown in Fig. 7C is the end result of performing a logical OR operation on the data stored in the processors memory addresses, as represented by the maps shown in Figs. 7A and 7B. Alternatively, a logical AND operation would discard all anomalies that are not common to both channels, which is the preferred embodiment. The composite map shown in Fig. 7D is the end result of performing a logical AND operation on the data stored in the processor's memory addresses, as represented by the maps shown in Figs. 7A and 7B. An exclusive OR operation discards anomalies that are detected on both

channels, keeping only those anomalies which are not commonly detected, as shown in Fig. 7E. These "suspect" particles would merit further examination with, inter alia, a high resolution microscope which could be employed on the system.

Referring again to Fig. 6, another manner in which to construct the maps, shown in Figs. 7A-C, is provided in which only those positions where the signal 37 crosses a certain threshold voltage level are stored in memory, while the remaining signal portions are discarded. For example, two threshold levels are shown: a fixed threshold level 39, and a variable threshold level 40. At threshold level 39, peaks 41-47 are registered and stored in memory. At the variable threshold level 40, as shown, only peaks 41, 43 and 45 are stored in memory. Using the threshold voltage level as shown, fewer positions are registered to form a map thereby making the subsequent processing faster, but at the risk of failing to detect smaller anomalies. The fixed threshold level 39 provides a greater number of positions being detected, but making the system slower. Typically, the fixed threshold level 39 is preset before scanning a wafer, and the variable threshold level is derived from the reflectivity/autoposition channel as described below.

Although the above-described example discussed comparing maps from signals generated by a pair of collector channels, this is not the only manner in which the system may operate. It is to be understood that maps formed from signals generated by the detector channels may also be compared to identify and classify anomalies, by performing algorithms and logical operations on the data, as described above. Comparing signals to a variable threshold level provides an instructive example, because the threshold level is

derived from the bright field reflectivity/autoposition channel 20, shown in Fig. 1.

The variable threshold level is dependent upon the local reflectivity. To that end, the bright field reflectivity/autoposition channel 20, is positioned in front of the beam 14 to collect specularly reflected light. The bright field signal derived from this channel carries information concerning the pattern, local variations in reflectivity and height. This channel is sensitive to detecting various defects on a surface. For example, the bright field signal is sensitive to representing film thickness variations, discoloration, stains and local changes in dielectric constant. Taking advantage of bright field signal sensitivity, the bright field signal is used to produce the variable threshold level 40, shown in Fig. 6. It is also used to produce an error height signal, corresponding to a variation in wafer height, which is fed to a z-stage to adjust the height accordingly, as well as to normalize the collector and detection channel signals, whereby the signals from the inspection channels each are divided by the bright field signal.

This removes the effect of dc signal changes due to surface variations. Finally, the bright field signal can be used to construct a reflectivity map of the surface. This channel is basically an unfolded Type I confocal microscope operating in reflection mode. It is considered unfolded because the illuminating beam and reflected beams, here, are not collinear, where as, in a typical reflection confocal microscope the illuminating and reflected beams are collinear.

Referring to Fig. 8, the imaging channel is shown to include a lens assembly 119 that images scattered light onto a one-dimensional or two-dimensional array of sensors 120 having pixels, e.g., charge-coupled

detectors. The array 120 is positioned so that the pixels collect light scattered by the illuminated spot around directions (e.g. direction 122) normal to the wafer surface 12 with the lens assembly 119 collecting upwardly scattered light. The spot 23 is focused and scanned in synchronism with the transferring of a charge contained in each pixel. This enables charging each pixel 121 independently of the remaining pixels, thereby activating one pixel 122 at a time with each pixel positioned so as to receive light scattered from a unique area of the sample surface, illuminated by the spot along the scan line. In this manner each pixel forms an image on the area illuminated by the spot, wherein there is a one-to-one correlation between a pixel and the spot position along the scan line. This increases the sensitivity of the system by improving the signal to background ratio. For example, it can be shown that for a PMT-based channel, the signal to background is defined as follows:

$$P_s/P_b = \sigma/A_b h$$

where  $P_s$  is the optical power scattered by a particle,  $P_b$  is the background optical power,  $A_b$  is the area of the beam on the surface and  $\sigma$  and  $h$  are constants. This shows that the ratio of the scattering cross section to the area of the beam determines the signal to background ratio.

With an imaging-based channel, all the scattered power from an anomaly is imaged onto one array element. The power distributed in background, however, is imaged over a range of elements, depending upon the magnification of the system. Assuming a linear magnification  $M$ , at the image plane the background power over an area is as follows:

19

$$M^2 A_b$$

providing an effective background power per array element as

$$P_b = P_i h A_c / M^2 A_b$$

5 where  $A_c$  is the area of an array element. Therefore, the signal to background ratio is given by the following:

$$P_s / P_b = M^2 \sigma / A_c h$$

10 This shows that the signal to background ratio is independent of the spot diameter, providing an improved signal to background ratio given by:

$$i = M^2 A_b / A_c$$

15 If imaging is not desired, another PMT-based collector channel similar to the one shown in Fig. 4 may be employed in lieu of the imaging channel, to collect upwardly scattered light.

20 Fig. 9A is a schematic view of an elliptical-shaped illuminated area (or spot) of a surface inspected by the system of this invention to illustrate the invention. As explained, the laser beam illuminating the surface inspected approaches the surface at a grazing angle, so that even though the illumination beam has a generally circular cross-section, the area illuminated is elliptical in shape such as area 210 in Fig. 9A. As  
25 known to those skilled in the art, in light beams such as laser beams, the intensity of the light typically does not have a flat distribution and does not fall off abruptly to zero across the boundary of the spot

illuminated, such as at boundary 210a of spot 210 of Fig. 9A. Instead, the intensity falls off at the outer edge of the illuminated spot at a certain inclined slope, so that instead of sharp boundaries such as boundary 210a illustrated in Fig. 9A, the boundary is typically blurred and forms a band of decreasing intensity at increasing distance away from the center of the illuminated area.

In many lasers, the laser beam produced has a Gaussian intensity distribution, such as that shown in Fig. 9B. Fig. 9B is a graphical illustration of the spatial distribution of the illumination intensity in the Y direction of a laser beam that is used in the preferred embodiment to illuminate spot 210 of a surface to be inspected as shown in Fig. 9A, and thus is also the illumination intensity distribution across spot 10 in the Y direction. As shown in Fig. 9B, the illumination intensity has been normalized so that the peak intensity is 1, and the illumination intensity has a Gaussian distribution in the X direction as well as in the Y direction. Points 212 and 214 are at spatial locations  $y_1$  and  $y_5$  at which points the illumination intensity drops to  $1/e^2$  of the peak intensity, where  $e$  is the natural number. The spot 210 is defined by the area within a boundary 10a where the illumination is  $1/e^2$  of that of the maximum intensity of illumination at the center of the spot. The lateral extent of the spot 210 may then be defined to be the boundary 210a. The size of the spot is then defined by means of the boundary. Obviously, other definitions of the boundary of a spot and of spot size are possible, and the invention herein is not restricted to the above definition.

To maintain uniform detection sensitivity, the scanning light beam is preferably caused to scan short

sweeps having a spatial span less than the dimension of the surface it is scanning, as illustrated in the preferred embodiment in Fig. 10, where these short sweeps are not connected together but are located so that they form arrays of sweeps. Preferably, the  
5 lengths of the sweeps are in the range of 2-25 mm.

The surface inspection system of this application will now be described with reference to Figs. 1 and 10. As shown in Fig. 10, system 200 includes a laser 222 providing a laser beam 224. Beam 224 is expanded by  
10 beam expander 226 and the expanded beam 228 is deflected by acousto-optic deflector (AOD) 230 into a deflected beam 232. The deflected beam 232 is passed through post-AOD and polarization selection optics 234 and the  
15 resulting beam is focused by telecentric scan lens 236 onto a spot 210 on surface 240 to be inspected, such as that of a semiconductor wafer, photomask or ceramic tile, patterned or unpatterned.

In order to move the illuminated area that is  
20 focused onto surface 240 for scanning the entire surface, the AOD 230 causes the deflected beam 232 to change in direction, thereby causing the illuminated spot 210 on surface 240 to be scanned along a sweep 250. As shown in Fig. 10, sweep 250 is preferably a straight  
25 line having a length which is smaller than the dimension of surface 240 along the same direction as the sweep. Even where sweep 250 is curved, its span is less than the dimension of surface 240 along the same general direction. After the illuminated spot has traversed  
30 along sweep 250, surface 240 of the wafer is moved by XY stage 24 (Fig. 1) parallel to the X axis in Fig 10 so that the illuminated area of the surface moves along arrow 252 and AOD 230 causes the illuminated spot to scan a sweep 250' parallel to sweep 250 and in an  
35 adjacent position spaced apart from sweep 250 along the

X axis to scan an adjacent sweep at a different X position. As described below, this small distance is preferably equal to about one quarter of the dimension of spot 210 in the X direction. This process is  
5 repeated until the illuminated spot has covered strip 254; at this point in time the illuminated area is at or close to the edge 254a. At such point, the surface 240 is moved by XY stage 24 along the Y direction by about the length of sweep 250 in order to scan and cover an  
10 adjacent strip 256, beginning at a position at or close to edge 256a. The surface in strip 256 is then covered by short sweeps such as 250 in a similar manner until the other end or edge 256b of strip 256 is reached at which point surface 240 is again moved along the Y  
15 direction for scanning strip 258. This process is repeated prior to the scanning of strip 254, 256, 258 and continues after the scanning of such strips until preferably the entire surface 240 is scanned. Surface 240 is therefore scanned by scanning a plurality of  
20 arrays of sweeps the totality of which substantially covers the entire surface 240.

The deflection of beam 232 by AOD 230 is controlled by chirp generator 280 which generates a chirp signal. The chirp signal is amplified by amplifier 282 and  
25 applied to the transducer portion of AOD 230 for generating sound waves to cause deflection of beam 232 in a manner known to those skilled in the art. For a detailed description of the operation of the AOD, see "*Acoustooptic Scanners and Modulators*," by Milton  
30 Gottlieb in Optical Scanning, ed. by Gerald F. Marshall, Dekker 1991, pp. 615-685. Briefly, the sound waves generated by the transducer portion of AOD 230 modulate the optical refractive index of an acoustooptic crystal in a periodic fashion thereby leading to deflection of  
35 beam 232. Chirp generator 280 generates appropriate



signals so that after being focused by lens 236, the deflection of beam 232 causes the focused beam to scan along a sweep such as sweep 250 in the manner described.

Chirp generator 280 is controlled by timing electronics circuit 284 which in the preferred embodiment includes a microprocessor. The microprocessor supplies the beginning and end frequencies f1, f2 to the chirp generator 280 for generating appropriate chirp signals to cause the deflection of beam 232 within a predetermined range of deflection angles determined by the frequencies f1, f2. The illumination sensor optics 20 and adaptive illumination control 292 are used to detect and control the level of illumination of spot 210. The optics 20 and adaptive illumination control 292 are explained in detail in U.S. Patent No. 5,530,550.

Detectors such as detectors 10a, 10b, 11a, 11b of Figs. 1 and 10 collect light scattered by anomalies as well as the surface and other structures thereon along sweeps such as sweep 250 and provide output signals to processor 500 in order to detect anomalies and analyze their characteristics.

Fig. 9C is a schematic view of three positions of the illuminated area or spot on a surface to be inspected to illustrate the scanning and data gathering process of system 200. As shown in Fig. 9C, at one instant in time, beam 238 illuminates an area 210 on surface 240. Spot 210 is divided into sixteen areas by grid lines x1-x5, y1-y5, where such areas are referred to below as pixels. In this context, the term "pixel" is defined by reference to the taking of data samples across the intensity distributions along the X and Y axes, such as that in Fig. 9C, and by reference to subsequent data processing. The pixel that is bounded by grid lines x2, x3 and y2, y3 is pixel P shown as a

shaded area in Fig. 9C. If there is an anomaly in this pixel P, and if the light illuminating pixel P has the intensity distribution as shown in Fig. 9B with a high intensity level between grid lines y2 and y3, light scattered by the anomaly will also have a high intensity. However, as the beam moves along the Y axis so that the area 210' is illuminated instead, pixel P will still be illuminated but at the lower intensity level of that between grid lines y1 and y2; in reference to Fig. 9B, the intensity of the illumination is that between grid lines y1 and y2 in Fig. 9B. Therefore, if the sampling rate employed by the data processor 500 in Figs. 1 and 10 for processing light detected by the collection or collector channels 10a, 10b, 11a, 11b is such that a data sample is taken when the illuminating beam is in position 210 and when the illuminating beam is in position 210', then two data samples will be recorded. Thus, for any pixel such as P, a number of data points will be taken, one when the illumination is at a higher level as illustrated by data point D2 in Fig. 9B and another one when the illumination is at a lower level, illustrated at data point D1 in Fig. 9B. If position 210 is not the starting position of the sweep 250, then two prior samples would have been taken prior to the time when the illuminating beam illuminates the surface 240 in position 210, so that the processor would have obtained two more data samples at points D3, D4 corresponding to the prior positions of the illuminating beam when light of intensity values between grid lines y3, y4 and between y4, y5 respectively illuminates such pixel P (grid lines y1 through y5 would, of course, move with the location of the spot). In other words, four separate data samples at points D1-D4 would have been taken of the light scattered by an

anomaly present in pixel P as the illumination beam illuminates pixel P when scanning along the Y direction.

In most laser beams, the beam intensity has a Gaussian intensity distribution not only in the Y direction but also in the X direction. For this reason, after the illuminating beam completes the scanning operation for scanning a sweep such as sweep 250 as shown in Fig. 10, and when the illuminating beam returns to position 274 for scanning the adjacent sweep 253 as shown in Fig. 10, it is desirable for the illuminated area along sweep 250' to overlap that of sweep 250 so that multiple samples or data points can again be taken also along the X direction as well as along the Y direction. Therefore, when the illumination beam is scanning along sweep 250' from starting position 274 as shown in Fig. 10, the area illuminated would overlap spot 210; this overlapping spot is 210'' as shown in Fig. 9C, where the spot 210'' is displaced along the X direction relative to spot 210 by one quarter of the long axis of the ellipses 210 and 210''.

Detector 120 includes a one-dimensional or two-dimensional array of sensors. To enable time delayed integration as described below, detector 120 employs a two-dimensional array of sensors as illustrated in Fig. 11.

In reference to Figs. 8 and 9C, in the preferred embodiment, the lens assembly 119 focuses the light scattered from only a portion of the illuminated spot 210 to a corresponding sensor in a two-dimensional array of sensors 120. By focusing the light scattered by only a portion of the illuminated spot onto a sensor, the sensitivity of the detection system of Fig. 8 is enhanced as compared to a system where light scattered by the entire spot is focused to a sensor. In the preferred embodiment, the lens assembly 119 focuses the

light scattered from a pixel, such as pixel P, towards a corresponding sensor in the array 120. As noted above, each pixel on the surface inspected will be illuminated four times in four adjacent and consecutive scans along the Y axis. Thus, in regard to pixel P, it was illuminated during the scan prior to the sweep 250, during sweep 250, during sweep 250' and the sweep subsequent to sweep 250'. Furthermore, the focusing of light from only a portion of the spot to a sensor also enables time delay integration to be carried out to enhance the signal-to-ratio in a manner described below.

For the purpose of illustration, it is assumed that when spot 210 is scanned along the sweep immediately prior to sweep 250, light scattered from the pixel P is focused by lens assembly 119 onto sensor 121(1)(3) of detector 120 in Fig. 11. Light scattered by pixels adjacent to and having the same Y coordinates as P will be focused by assembly 119 to other sensors in the linear array or line 121(1) of sensors in Fig. 11. In order for the spot 210 to be then subsequently scanned along sweep 250, XY stage 24 moves the wafer surface by a distance substantially equal to 1/4 of the length of the long axis of spot 210, so that the lens assembly 119 will now focus the light scattered by pixel P onto sensor 121(2)(3) instead of 121(1)(3), and light scattered by P's adjacent pixels and with the same Y coordinates to sensors along line 121(2). As shown in Fig. 11, sensor 121(1)(3) is electrically connected to sensor 121(2)(3) (e.g. by a wire); in the same vein, the remaining sensors in line 121(1) are similarly electrically connected to corresponding sensors in line 121(2) as shown in Fig. 11. Similarly, the sensors in line 121(2) are electrically connected to corresponding sensors in line 121(3) and so on for all adjacent pairs of lines of sensors in detector 120.

To enable time delayed integration, processor 500 causes the signal in sensor 121(1)(3) obtained by detecting light scattered by pixel P during the previously described scan to be transferred to sensor 121(2)(3), so that the signal obtained during the prior scan will be added to that obtained by sensor 121(2)(3) from detecting the light scattered by pixel P during sweep 250. Similarly, processor 500 causes the thus accumulated signal in sensor 121(2)(3) to be transferred to sensor 121(3)(3) prior to the sweep 250', so that the signal thus accumulated can be added to that obtained by sensor 121(3)(3) by detecting the light scattered from pixel P during sweep 250'. In this manner, time delayed integration is performed by accumulating the signals obtained from light scattering from pixel P during four sequential sweeps and is read out as the output signal for such pixel. The same can be done for other pixels on the surface of the wafer. While in the preferred embodiment, the amount of overlap and the sampling rate are controlled so that each illuminating spot is divided into 16 pixels, it will be understood that the spot may be divided into a smaller or greater number of pixels by altering the amount of overlap between sequential sweeps and by altering the sampling rate; such and other variations are within the scope of the invention.

The above-described process may be performed for all of the pixels in the illuminated spot where processor 500 simply causes all of the signals in each linear array or line of sensors, such as line 121(1) to be transferred to corresponding sensors in the next line 121(2), and this process is carried out for all of the lines, from line 121(1) to the next to the last line 121(N-1), so that time delay integration is performed for all of the pixels. The number of sensors in each line is preferably large enough to cover all the pixels

in each sweep. In order to avoid edge effects, it may be desirable to include enough lines of sensors to cover all of the possible positions of the pixels in the illuminated spot along the X direction of the wafer.

5       As described above, signals obtained by light scattering from the pixel are accumulated over four sequential sweeps. The final accumulated signal is then read out by processor 500 as the output of detector 120 for such pixel. Processor 500 then constructs a defect  
10   map from a two-dimensional array of such accumulate signals from the outputs of detector 120. Such map may be compared to the defect maps obtained by processor 500 from detectors 10a, 10b, 11a and 11b to obtain an AND, a union and an XOR map for the purpose of identifying  
15   anomalies. Thus, an AND map would comprise only of anomalies present in a map from one detector and in a map or maps from one or more of the remaining detectors. A union map comprises of anomalies present in at least one of the maps of two or more detectors. An XOR map  
20   comprises of anomalies present in the map of only one detector but not in the map or maps of the remaining detectors. As noted above, the above maps are useful for classifying defects. Thus, if an anomaly is present in the map of one detector but not in the map of the  
25   other symmetrically placed detector, then the anomaly is probably not symmetrical. Or if an anomaly is present in the map of detectors 10a, 10b for detecting laterally scattered light but not in the maps of detectors 11a, 11b for detecting forward scattered light, then the  
30   anomaly may be more likely to be a pattern defect than a particle.

      The XY stage 24 is controlled by a controller (not shown) in communication with processor 500. As this controller causes the stage 24 to move the wafer by a  
35   quarter of the X dimension of the spot 210, this is

communicated to processor 500, which sends control signals to detector 120 to cause a transfer of signals between adjacent lines of sensors and sends control signals to timing electronics 284 as shown in Fig. 10. Electronics 284 in turn controls the chirp rate of chirp generator 280 so that the transfer of signals between adjacent lines of sensors in detector 120 will have occurred prior to the scanning of the illuminated spot.

In the preferred embodiment, the illuminated spot has a spot size whose minimum dimension is in the range of about 2 to 25 microns.

Referring again to Fig. 1, an alignment and registration channel 22 is provided. Instead of the design in Figs. 8 and 11, the channel 21 may also have the same design as a basic collection channel 10a, 10b and 11a, 11b, but it is positioned in the plane of incidence so that the signal produced from the patterns or features on the wafer's surface is at a maximum. The signal obtained is used to properly align the wafer surface 12 so that the streets on the features are not oblique with the scan line. This also reduces the amount of signal collected by the collector channels, resulting from scattering by patterns.

In operation, the beam 14 is scanned over the surface 12, producing both scattered and specularly reflected light, which are simultaneously detected. The light scattered laterally, forwardly and upwardly is simultaneously detected by the collector channels and the imaging system. The specularly reflected light from the wafer's surface 12 is detected by the bright field reflectivity/autoposition channel 20. Light detected by the inspection channels is converted into electrical signals which are further processed by dedicated electronics, including a processor 500. The processor 500 constructs maps from the signals produced by the inspec-

tion channels. When a plurality of identical dies are present on the wafer surface 12, a detection method may be employed whereby periodic feature comparisons are made between adjacent die. The processor compares the maps from the inspection channels either in the analog domain or digitally, by performing logical operations on the data, e.g., AND, OR and XOR, in the manner described above, to detect anomalies. The processor forms composite maps, each representing the detected anomalies by a single group of symmetrically disposed collector channels. The composite maps are then compared so that the processor may classify the anomalies as either a pattern defect or particulate contamination. Typically, the wafer surface 12 has been aligned so that the streets on the die are not oblique with respect to the scan line, using the information carried by the electrical signal produced by the alignment/registration channel. Proper alignment is a critical feature of this invention, because periodic feature comparison is performed to locate anomalies.

While the above described apparatus and method for detecting anomalies has been described with reference to a wafer surface, it can easily be seen that anomaly detection is also possible for photomasks and other surfaces, as well as producing reflectivity maps of these surfaces. The invention is capable of detecting anomalies of submicron size and affords the added advantage of classifying the type of anomaly and identifying its size and position on the surface. This information is highly useful to wafer manufacturers as it will permit locating the step in the wafer manufacturing process at which point an anomaly occurs.



WHAT IS CLAIMED IS:

1. An optical scanning system for detection of anomalies, such as particles or pattern defects, on a surface comprising:

5 means for directing a focused beam of light onto a sample surface to produce an illuminated spot thereon;

means for scanning the spot across the surface along a first scan line;

10 a first detector positioned adjacent to said surface to collect scattered light from the spot, wherein the detector includes a linear or two-dimensional array of sensors; and

15 means for focusing scattered light from the illuminated spot at each of a plurality of positions along the scan line onto a corresponding sensor in the array.

2. The system of claim 1, said detector positioned to detect light scattered from the spot around a normal direction to the surface.

20 3. The system of claim 1, said detector including a two-dimensional array of sensors that includes at least a first line of sensors, wherein said focusing means focuses light scattered from the spot at said plurality of positions along the first scan line onto  
25 the first line of the sensors in the array.

4. The system of claim 3, said array further including at least a second line of sensors, wherein said means for scanning scans the spot along at least a second scan line adjacent to the first scan line after  
30 scanning the spot along the first scan line, said system further comprising means for synchronizing a transfer of signals from said first line of sensors to the at least

one second line of sensors, said focusing means focusing light scattered from the spot at a plurality of positions along the at least second scan line onto said at least one second line of sensors, thereby performing  
5 time delayed integration of signals at the array.

5. The system of claim 4, further comprising means for controlling scan speed of the scanning means and said synchronizing means to enable said time delay integration.

10 6. The system of claim 5, said scanning means including an acoustic-optic deflector having a chirp rate, said controlling means controlling the chirp rate and timing of the transfer of signals by the synchronizing means.

15 7. The system of claim 4, wherein said focusing means focuses light scattered from only a portion of the spot onto a corresponding sensor.

20 8. The system of claim 7, wherein said plurality of positions of the spot along the second scan line overlaps those along the first scan line.

9. The system of claim 8, wherein said portion is about 1/16 of the spot and said plurality of positions of the spot along the second scan line overlaps about 1/4 of those along the first scan line.

25 10. The system of claim 1, wherein said spot has a spot size whose minimum dimension is in the range of about 2 to 25 microns.

11. The system of claim 1, wherein said scanning means scans the spot along a serpentine scan path, said path including a plurality of arrays of scan path segments, wherein each of at least some of such scan path segments has a span shorter than the dimensions of the surface, said scan path segments having lengths in the range of about 2 to 25 mm.

12. The system of claim 1, further comprising a first group of detectors oriented to receive light scattered in a direction less than 30 degrees above the surface and symmetrically disposed on opposite sides of the scanning beam at an azimuthal angle of 75 to 105 degrees, with respect to the scanning beam.

13. The system of claim 12, further comprising a second group of detectors oriented to receive light scattered in a direction less than 30 degrees above the surface and symmetrically disposed on opposite sides of the scanning beam at an azimuthal angle of 30 to 60 degrees, with respect to the scanning system.

14. The system of claim 1, further including an autoposition detector for collecting specularly reflected light from the spot, the autoposition detector having a means for measuring a change in height of the surface.

15. The system of claim 1, further comprising:  
a group of a plurality of detectors symmetrically positioned about the surface, to collect forwardly and/or laterally scattered light, each of the plurality of detectors producing a signal representing scattered light;

means for producing a plurality of maps from said signals and from an output of said first detector; and means for comparing at least two of the maps for identifying anomalies.

5           16. The system of claim 15, said comparing means providing an AND map that comprises only of anomalies present in said at least two of the maps.

10           17. The system of claim 15, said comparing means providing a union map that comprises of anomalies present in either one of said at least two of the maps.

18. The system of claim 15, said comparing means providing a XOR map that comprises only of anomalies present in only one but not both of said at least two of the maps.

15           19. The system of claim 15, said comparing means comparing at least two of the maps for identifying pattern defects and particles.

20           20. The system of claim 1, said directing means directing said focused beam at a grazing angle of incidence onto the sample surface.

21. An optical scanning method for detection of anomalies, such as particles and pattern defects, on a surface, comprising the steps of:

25           directing a focused beam of light onto a sample surface to produce an illuminated spot thereon;

          scanning the spot across the surface along a first scan line;

          positioning a first detector adjacent to said surface to collect scattered light from the spot,

wherein the detector includes a one-dimensional or two-dimensional array of sensors; and

5 focusing scattered light from the illuminated spot at each position along the scan line onto a corresponding sensor in the array.

22. The method of claim 21, said positioning step positioning the detector to detect light scattered from the spot around a normal direction to the surface.

10 23. The method of claim 21, said first detector including a two-dimensional array of sensors that includes at least a first line of sensors, wherein said focusing step focuses light scattered from the spot at positions along the first scan line onto a first line of the sensors in the array.

15 24. The method of claim 23, said array further including at least a second line of sensors, wherein said step for scanning scans the spot along at least a second scan line adjacent to the first scan line after scanning the spot along the first scan line, said method  
20 further comprising synchronizing a transfer of signals from said first line of sensors to the second line of sensors, said focusing step focusing light scattered from the spot along the at least second scan line onto said second line of sensors, thereby performing time  
25 delayed integration of signals at the array.

25. The system of claim 24, further comprising controlling scan speed of the scanning step and timing of the transfer of signals in the synchronizing step to enable said time delay integration.

26. The system of claim 25, said scanning step employing an acoustic-optic deflector having a chirp rate, said controlling step controlling the chirp rate and timing of the transfer of signals in the  
5 synchronizing step.

27. The method of claim 24, wherein said focusing step focuses light scattered from only a portion of the spot onto a corresponding sensor.

28. The method of claim 27, wherein positions of  
10 the spot along the second scan line overlaps those along the first scan line.

29. The method of claim 28, wherein said portion is about 1/16 of the spot and positions of the spot along the second scan line overlaps about 1/4 of those  
15 along the first scan line.

30. The method of claim 21, wherein said spot has a spot size whose minimum dimension is in the range of about 2 to 25 microns.

31. The method of claim 21, wherein said scanning  
20 step scans the spot along a serpentine scan path, said path including a plurality of arrays of scan path segments, wherein each of at least some of such scan path segments has a span shorter than the dimensions of the surface, said scan path segments having lengths in  
25 the range of about 2 to 25 mm.

32. The method of claim 21, further comprising a first group of detectors oriented to receive light scattered in a direction less than 30 degrees above the surface and symmetrically disposed on opposite sides of

the scanning beam at an azimuthal angle of 75 to 105 degrees, with respect to the scanning beam.

33. The method of claim 21, further comprising:  
positioning a group of a plurality of detectors  
5 symmetrically positioned about the surface, to collect  
forwardly and/or laterally scattered light, each of the  
plurality of detectors producing a signal representing  
scattered light;  
producing a plurality of maps from said signals and  
10 from an output of the first detector; and  
comparing at least two of the maps for identifying  
anomalies.

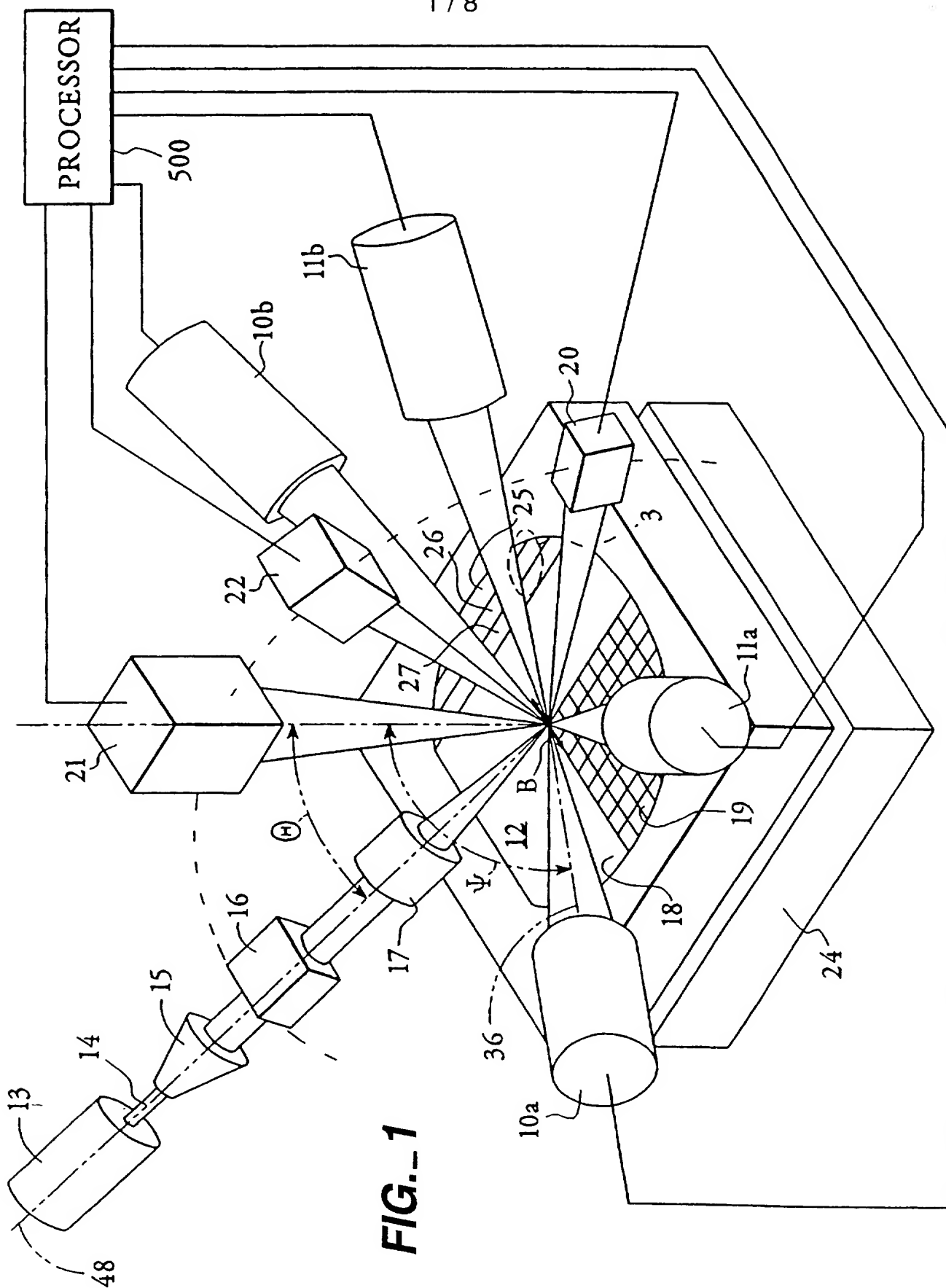
34. The method of claim 33, said comparing step  
providing an AND map that comprises only of anomalies  
15 present in said at least two of the maps.

35. The method of claim 33, said comparing step  
providing a union map that comprises of anomalies  
present in either one of said at least two of the maps.

36. The method of claim 33, said comparing step  
20 providing a XOR map that comprises only of anomalies  
present in only one but not both of said at least two of  
the maps.

37. The method of claim 33, said comparing step  
comparing at least two of the maps for identifying  
25 pattern defects and particles.

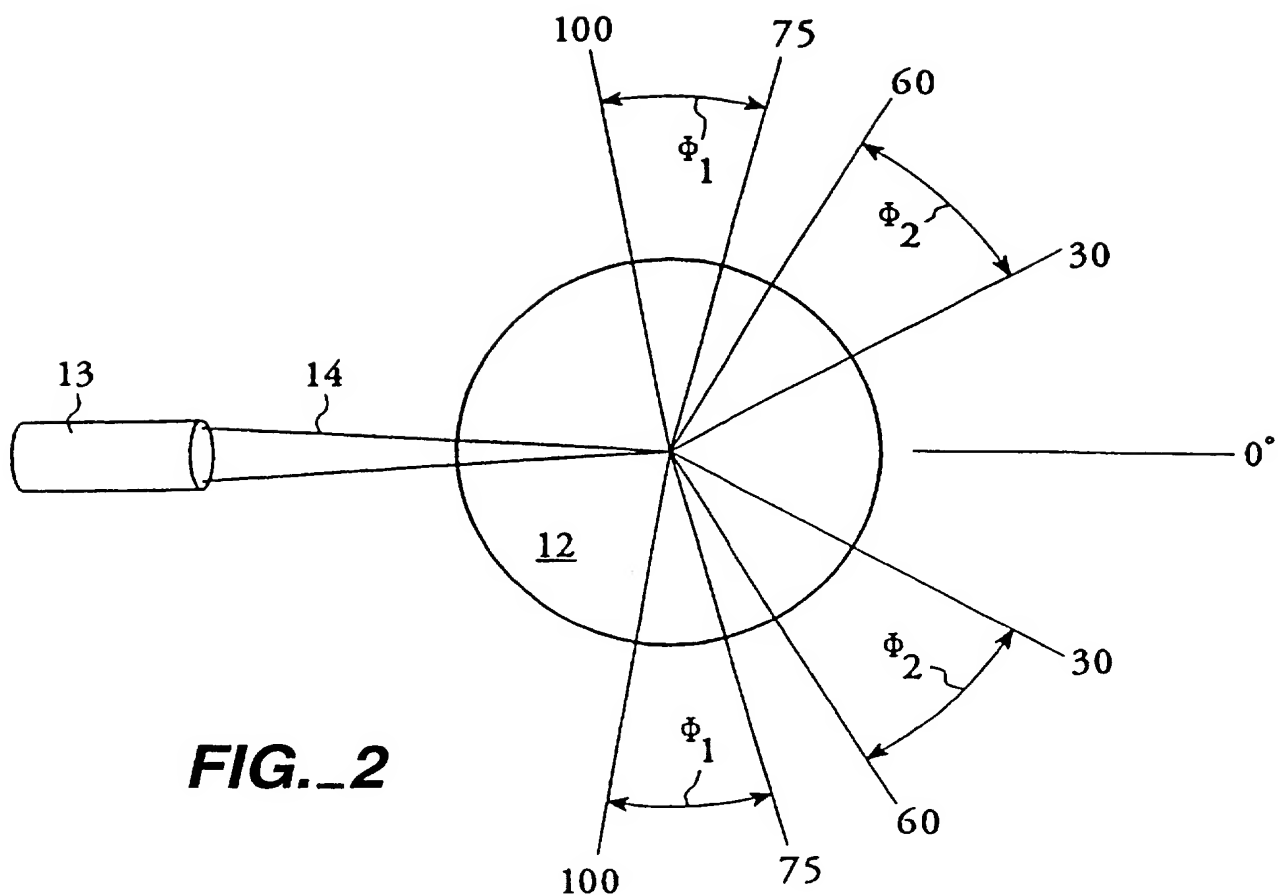
38. The method of claim 21, said directing step  
directing said focused beam at a grazing angle of  
incidence onto the sample surface.



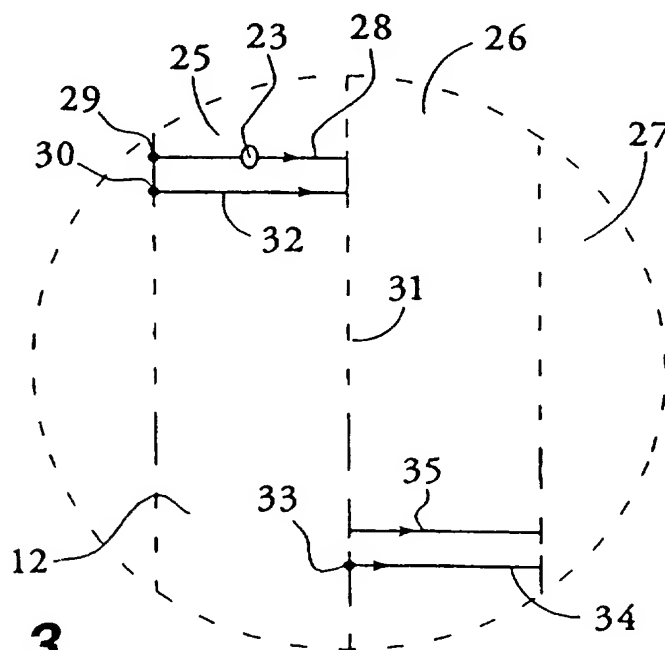
**FIG. 1**



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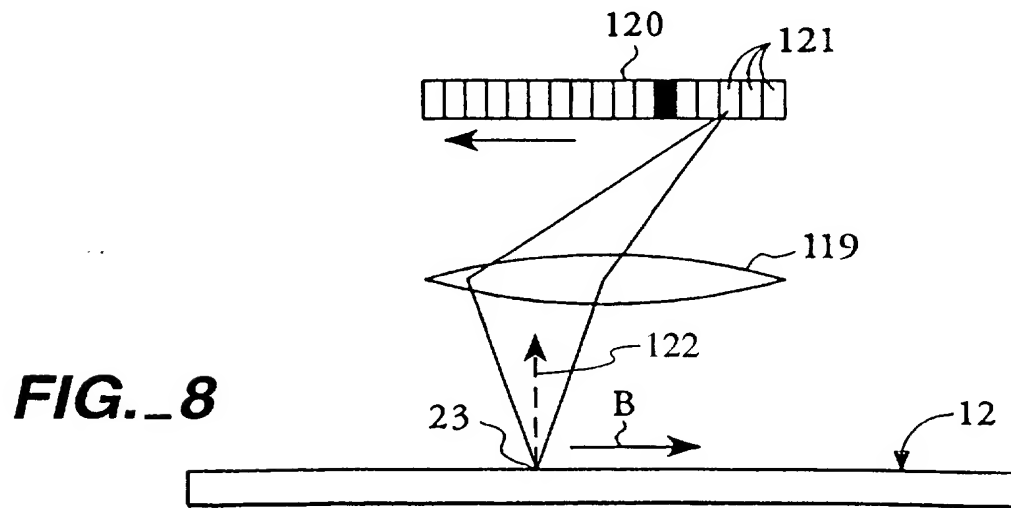
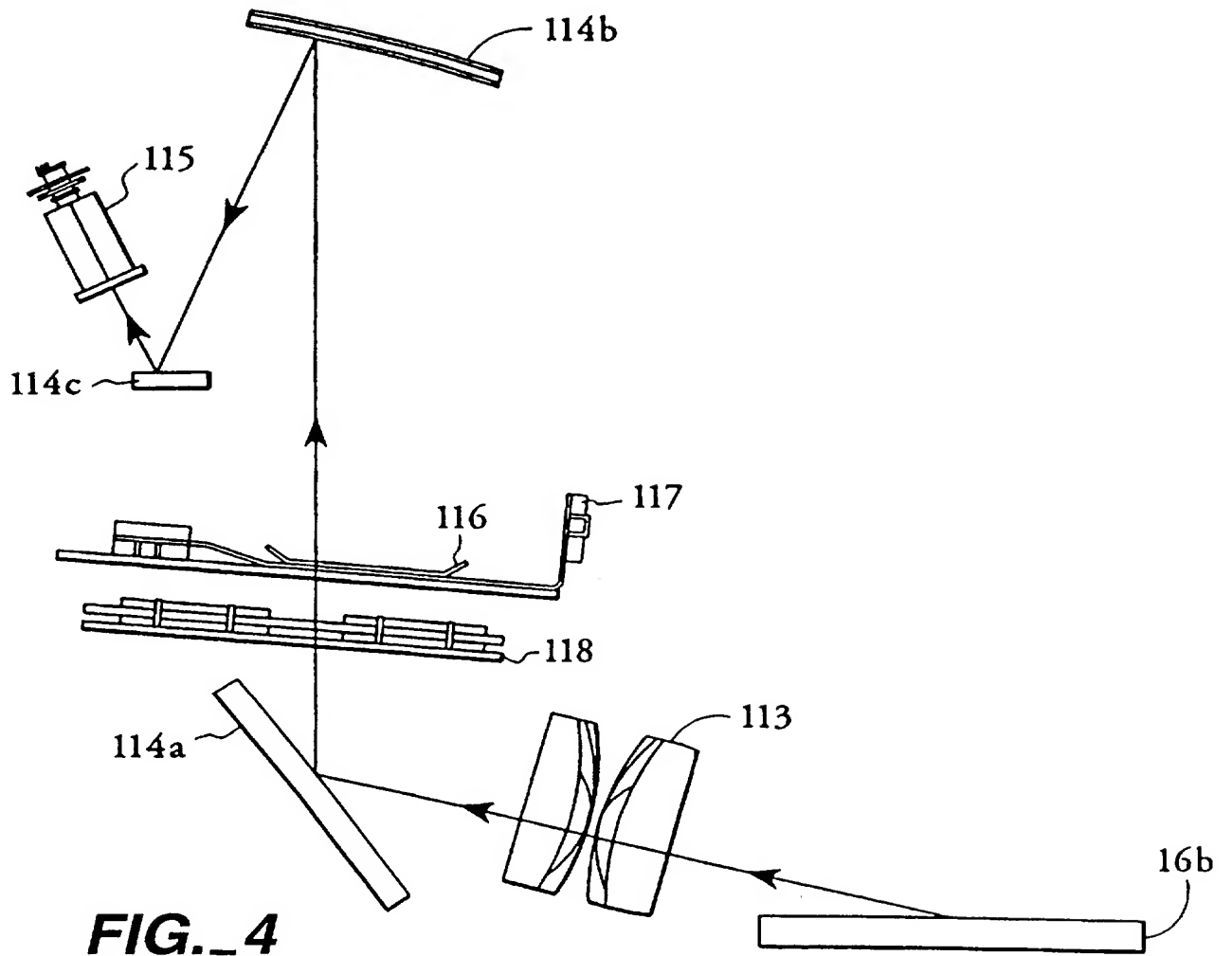


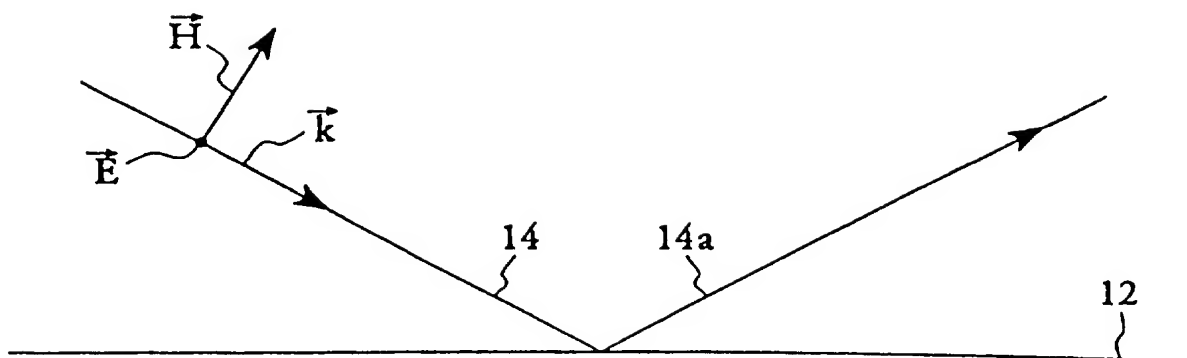
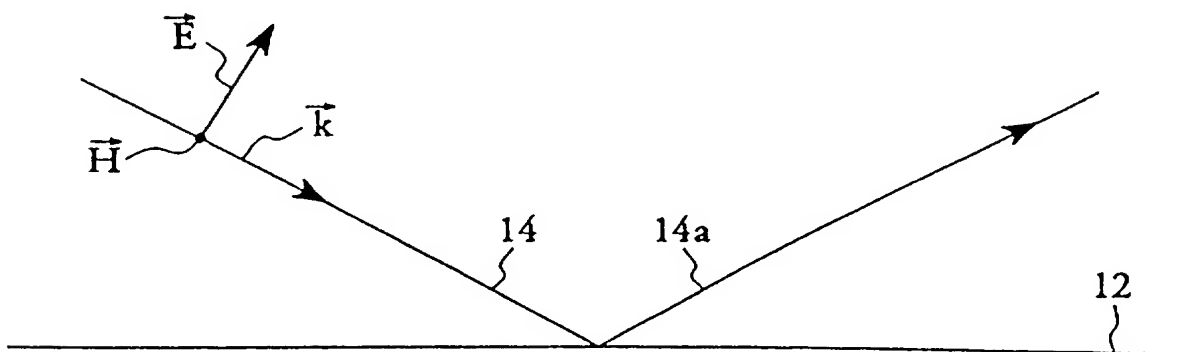
**FIG. 2**



**FIG. 3**

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**FIG.\_5A****FIG.\_5B**

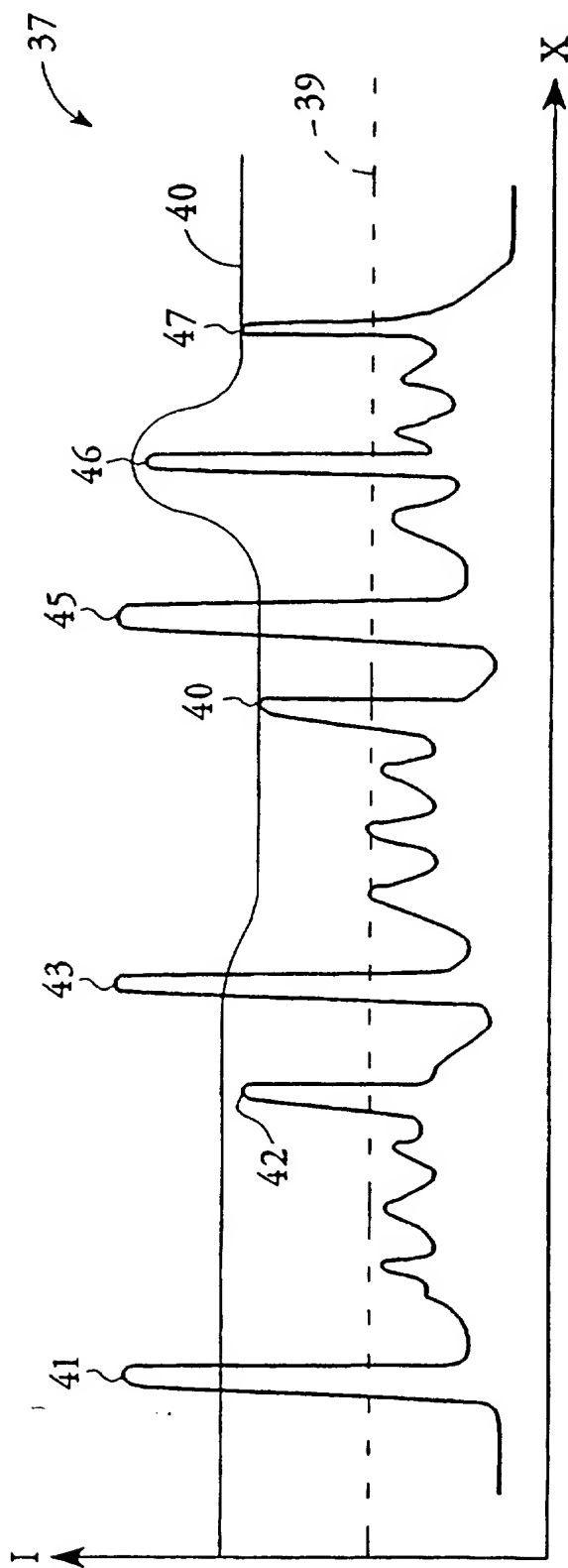


FIG. 6

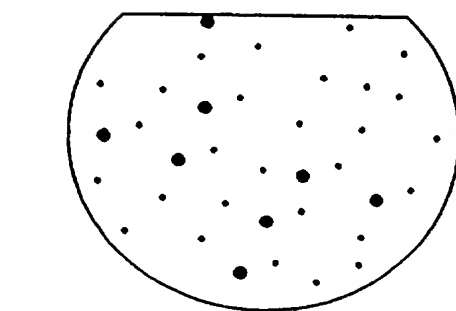


FIG. 7A

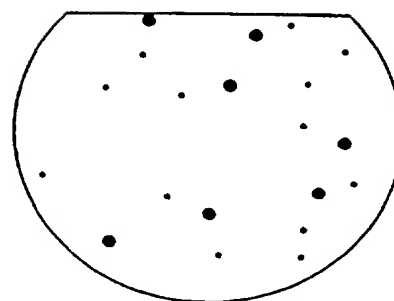


FIG. 7B

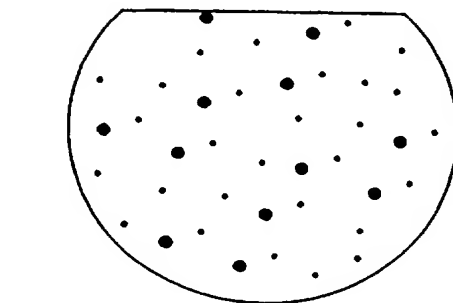


FIG. 7C

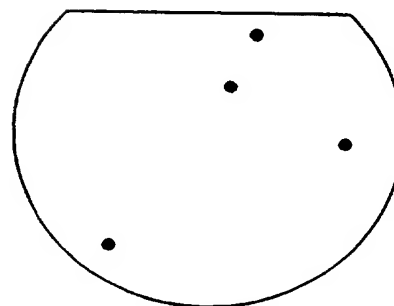


FIG. 7D

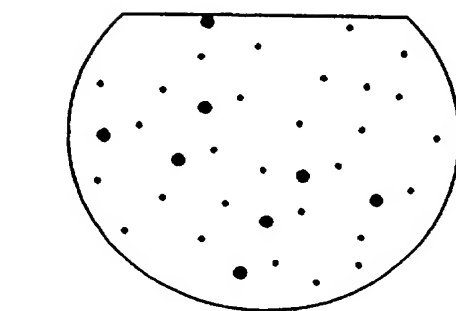
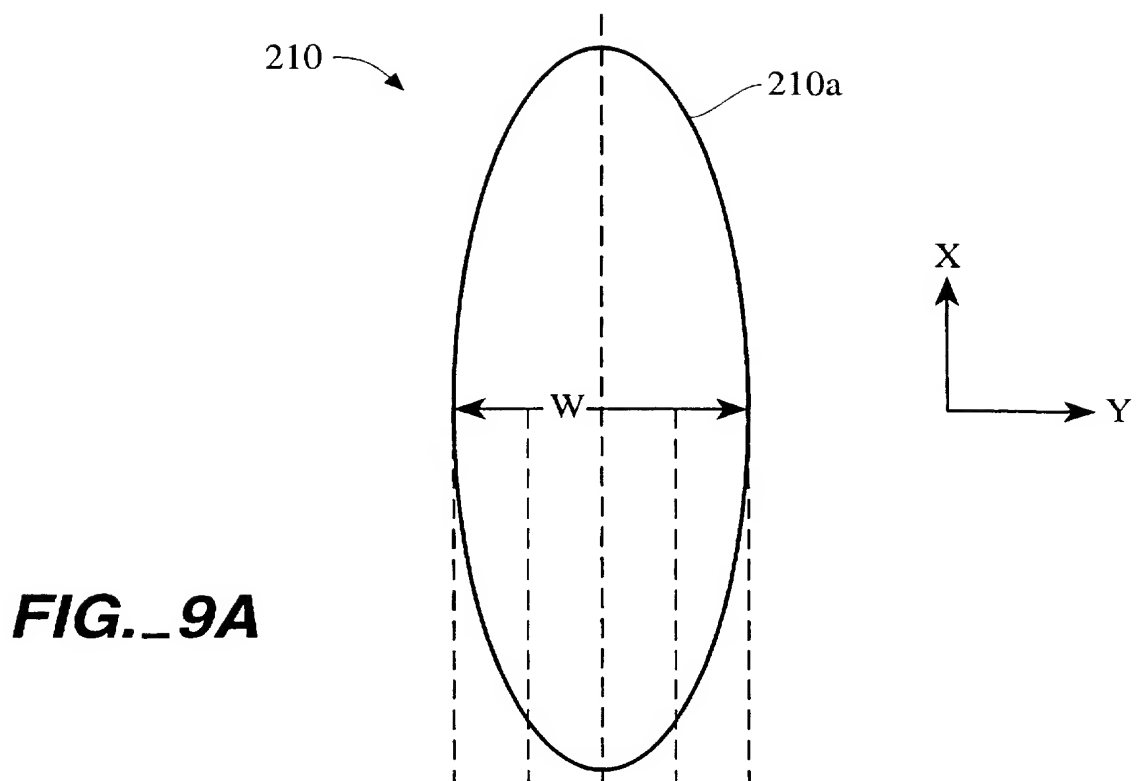
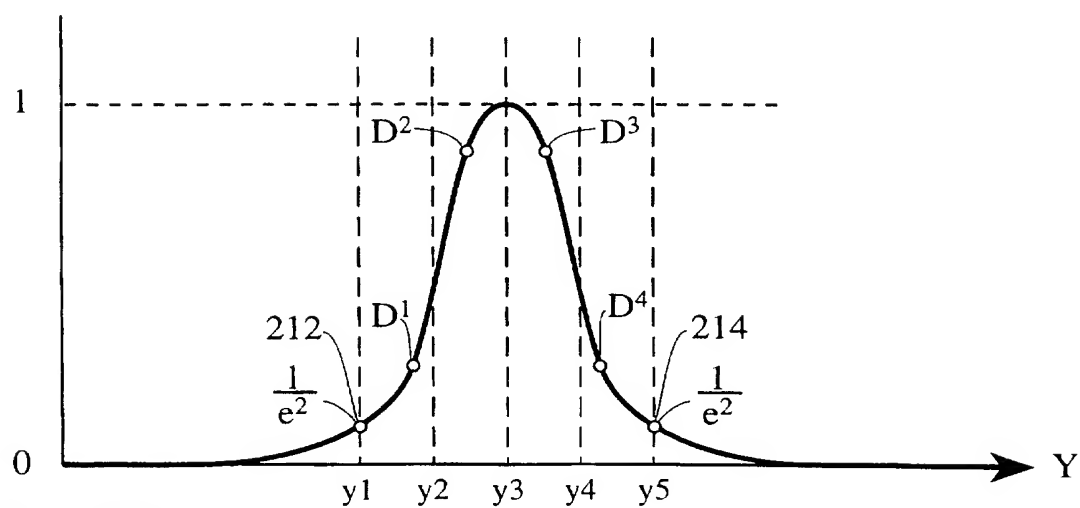


FIG. 7E

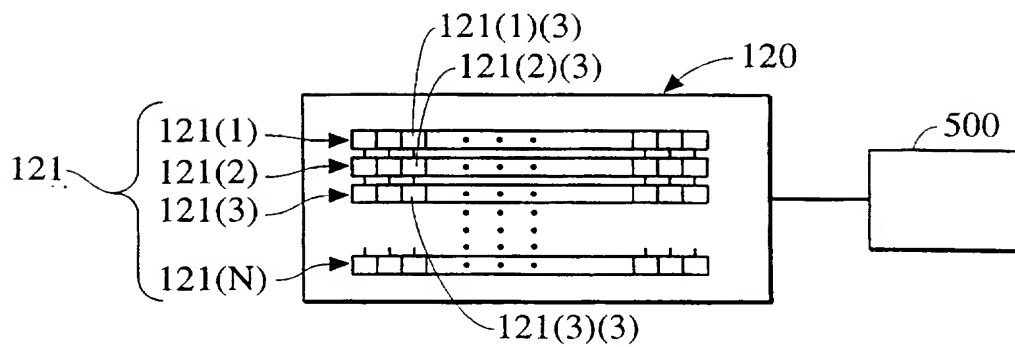
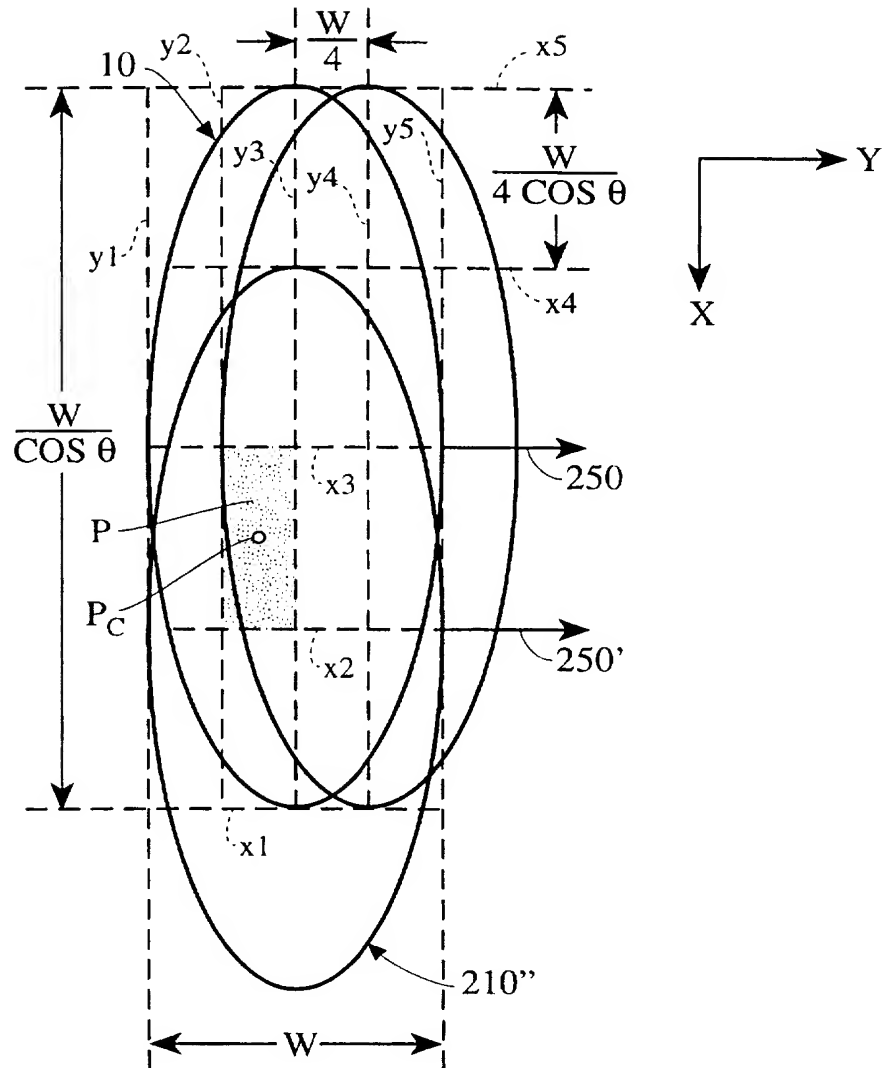


**FIG. 9A**

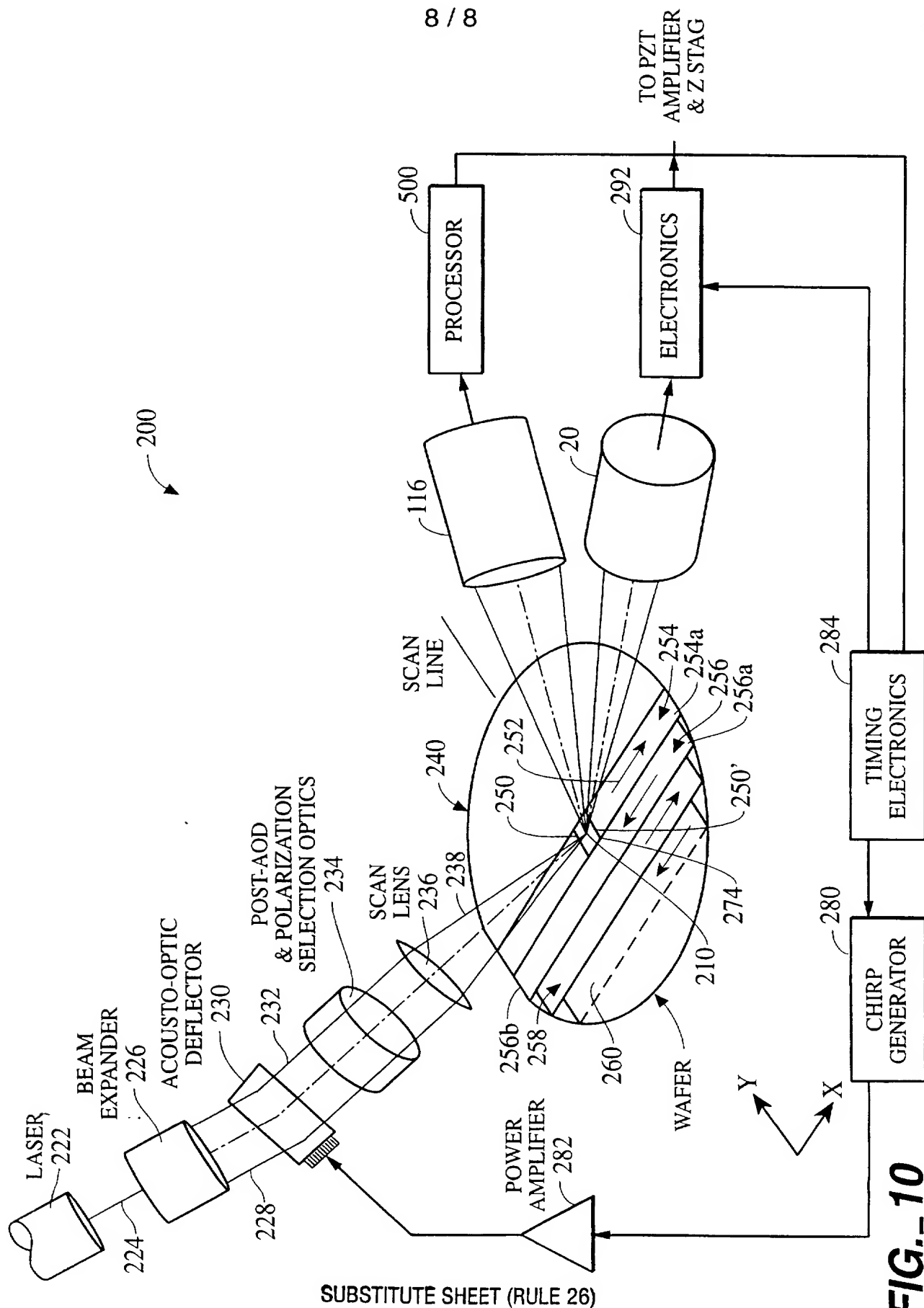


**FIG. 9B**

**FIG.\_9C**



**FIG.\_11**



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US97/09650

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) : G01N 21/00

US CL : 356/237

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 356/237, 337-343

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	NIKOONAHAD et. New Laser Scanning Techniques for Wafer Inspection. SPIE February 1995, Vol. 2638, pages 285-301.	1-38
Y	ALUMOT et al. Dual sensor technology for high-speed detection of 0.1 micron defects. SPIE. 1993, Vol.1926, pages 1-12	1-38

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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*P* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

08 AUGUST 1997

Date of mailing of the international search report

29 AUG 1997

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